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Approaches and mechanisms for ecologically based pest management across multiple scales

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ABSTRACT

The past 50 years have seen substantial change of agroecosystems in the world, including an intensified use of agrochemicals and expansion of cropland, resulting in a rapid loss of biodiversity and a reduction of ecosystem services. The effects of these changes, at both the field and landscape scale, on ecologically based pest management (EBPM) in agroecosystems have become increasingly important. Here, we review the theories, important approaches and mechanisms of habitat management practices (at multiple spatial scales) that can be applied to facilitate EBPM in crop fields and even over larger landscapes. In particular, we discuss links between pest outbreaks and rapid changes of habitat composition at local and regional scales. We also summarize recent progress of habitat management and their application to pest management, which is an activity that we believe must be implemented at multiple spatial scales to successfully conserve ecosystem services and address environmental issues related to crop pest control.

Contents

1. Introduction

Landscape-level patterns of land use can affect both ecosystem processes and local food web structures (Gagic et al., 2012; Zhao et al., 2015). Over the past 50 years, rapid development, urbanization and agricultural intensification have resulted in extensive conversion of land cover, resulting in habitat loss and fragmentation of rural and semi-natural landscapes, which has in turn reduced biodiversity and natural biocontrol in agroecosystems (Bianchi et al., 2006; Tscharntke et al., 2007). This has been the result of change both in crop fields and, at the landscape level, changes around crops. In fields, the increased use of fertilizer and pesticides has changed plant nutrition levels and soil structure in ways that favor agricultural pests (Gagic et al., 2012; Jonsson et al., 2012). Concurrently, at the landscape level, cropland expansion into formerly semi-natural habitats has altered the vegetative

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composition at this spatial scale, affecting arthropod communities and facilitating outbreaks of agricultural pests (Macfadyen et al., 2011; Tscharntke et al., 2012b).

Although many tactics have been applied to enhance biodiversity conservation in agricultural landscapes, largely by adding semi-natural habitats (Brevault et al., 2014; Deguine and Penvern, 2014), their effects on the functional biodiversity of natural enemies are still unclear, especially for enhancing the efficacy of biocontrol through boosting natural enemies. In addition, how to simultaneously improve ecosystem healthy and functional biodiversity through habitat management has yet to be explored (Landis et al., 2000; Macfadyen et al., 2012). Therefore, we focused on summarizing methods for management aiming at boosting biocontrol through enhancing natural enemies and their associated functional biodiversity, which could help to narrow the gap between sustainable agriculture and biodiversity conservation (Tscharntke et al., 2012b).

2. Sustainable agriculture and ecologically based pest management

To reverse aforementioned negative trends, ecologically based pest management (EBPM) proposes strategies that link agricultural fields to the broader landscape through deliberate landscape design and modification (Landis et al., 2000; Altieri and Nicholls, 2003b). Such habitat management has been successfully applied to pest population management at both the local and the broader landscape levels (Beduschi et al., 2015; Schneider et al., 2015). When using habitat management to recover the biocontrol potential of natural enemies in modern agroecosystems, it is important to understand the effects of agricultural intensification, including agrochemical inputs, within the context of field and cropland expansion at the landscape scale (Fig. 1).

With the development and improvement of spatial ecology (3S technology: Remote Sensing System, Geographical Information System, and Global Positioning System), habitat composition and landscape structure across multiple spatial scales can now be analyzed quantitatively with ease. Therefore, the relationship between landscape structure and the tritrophic interactions of crops, pests, and natural enemies can be thoroughly investigated in insect ecology (O'Rourke et al., 2011). However, while many studies have indirectly determined the effects of agricultural intensification on pest population control by natural enemies at either a local or a landscape scale, none have examined both, due to the different paradigms involved (Batary et al., 2012; Zhao et al., 2013a).

The EBPM emphasizes that habitat management to control crop pests should consider effects of controls applied on other ecosystem services such as environmental issues, pollination, and biodiversity, especially at the landscape or regional scales (Koul and Cuperus, 2006; Brewer and Goodell, 2012; Macfadyen et al., 2012). In China, changes in the agricultural landscapes have led to both spatial and temporal rearrangements of croplands and semi-natural habitats. The result has been a mosaic cycle of plantings and greater fragmentation of semi-natural habitats (Thies et al., 2008; Zhao et al., 2012).

In addition to the influence of such landscape-level changes on the abundance and intraspecific interactions between pests and natural enemies, agricultural practices (e.g., increasing fertilizer

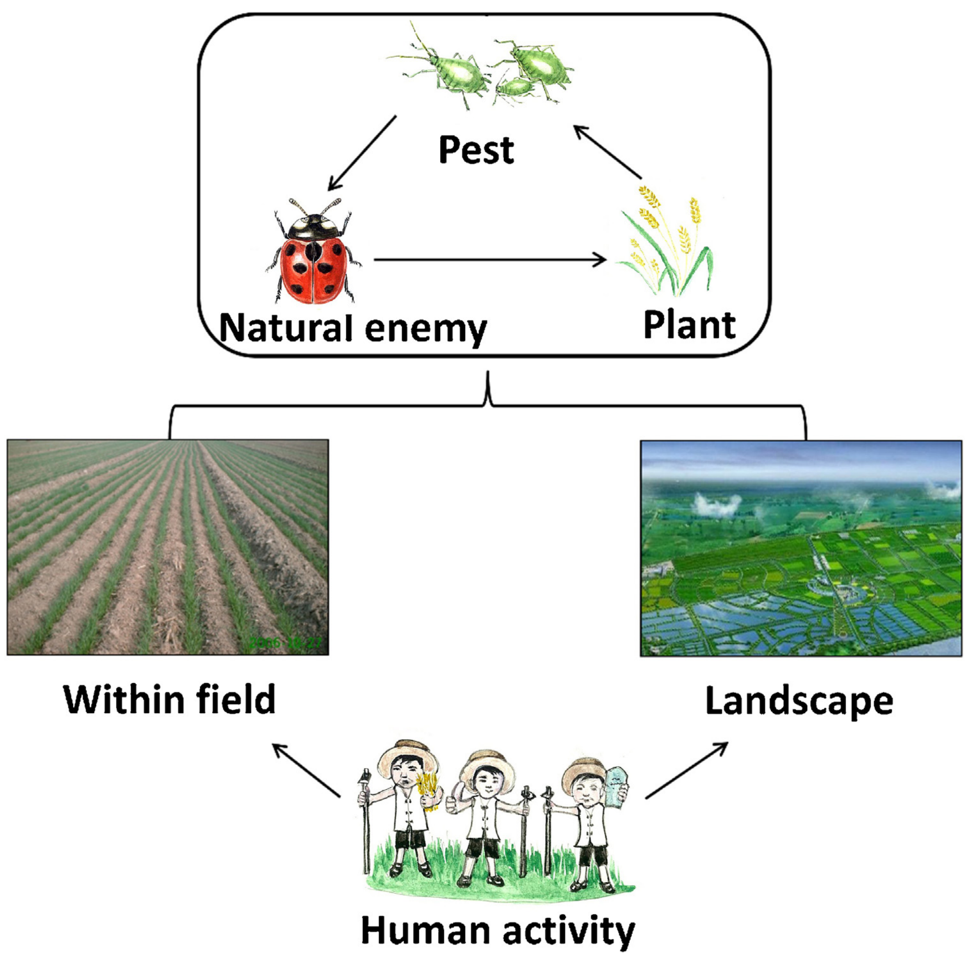

Fig. 1. The processes of human activity affecting insect community through agricultural practice within field and at landscape scale.

inputs) at the field level also influence the growth and development of agricultural pests by enhancing the amino acids and sugars available in plants (Robert, 2002; Lehmann et al., 2003). Indeed, earlier studies have suggested that EBPM should address influences that operate at multiple spatial scales, and should also consider pest management in a holistic framework (Landis et al., 2000; Tscharntke et al., 2007; Fig. 1). Such a framework should include all ecosystem services derived from croplands and adjacent habitats as well as environmental pollutants coming from crop fields, rather than having a narrow focus on only the effectiveness and sustainability of pest control methods (Jonsson et al., 2008; Tscharntke et al., 2007). Here, we examine how field level pest management practices can best be integrated into landscape management in ways that promote both ecological services and pest control. We first review in-field ecological pest control practices and then practices that operate outside crop fields at the landscape level (Fig. 1). We conclude with a discussion of how to integrate these two levels of pest management.

3. Approaches and mechanisms of EBPM

3.1. Local-scale practices for EBPM

Agricultural practices promoting EBPM within fields include crop rotation, cover cropping, no-tillage practices, and other habitat management techniques, all of which have become widely used in orchards and other crop fields throughout the USA and Europe (Shrestha et al., 2002; dos Santos et al., 2011; Mirsky et al., 2012; Fig. 2). In China, intercropping technology has been developed to achieve EBPM by enhancing plant diversity, which also could retain high levels of crop production (Zhao et al., 2013b). Studies have also demonstrated that healthy soil with favorable biological, physical, and chemical properties can produce a healthy crop with few external inputs or adverse ecological effects (van Bruggen and Semenov, 2000; Herencia et al., 2011; Altieri et al., 2012; Sapkota et al., 2012). These techniques seek to manipulate field microenvironments and crop nutrition in ways that enhance natural enemies while suppressing pests. In addition, it is now clear that increasing agrochemical inputs (fertilizer and pesticides) to improve crop production has frequently had unanticipated negative effects on pest abundance and the arthropod community in crop fields and surrounding vegetation (Bourn and Prescott, 2002; Altieri and Nicholls, 2003a; Amtmann et al., 2008; Woltz et al., 2012). Increasing nitrogen availability, often an important limiting factor in an agroecosystem, may also increase the development rate and fecundity of phytophagous insects, especially in a simplified landscape, leading to increased pest densities in intensive agriculture (Sikora, 1992; Ratnadass et al., 2012).

Furthermore, low pesticide doses (sub-lethal) may actually enhance the growth, development, and oviposition of some phytophagous insects, leading to outbreaks of these agricultural pests (Morse, 1998; Liang et al., 2013; Roubos et al., 2014). Integrated pest management (IPM) systems have, since 1959, successfully developed a series of chemical, physical and biological

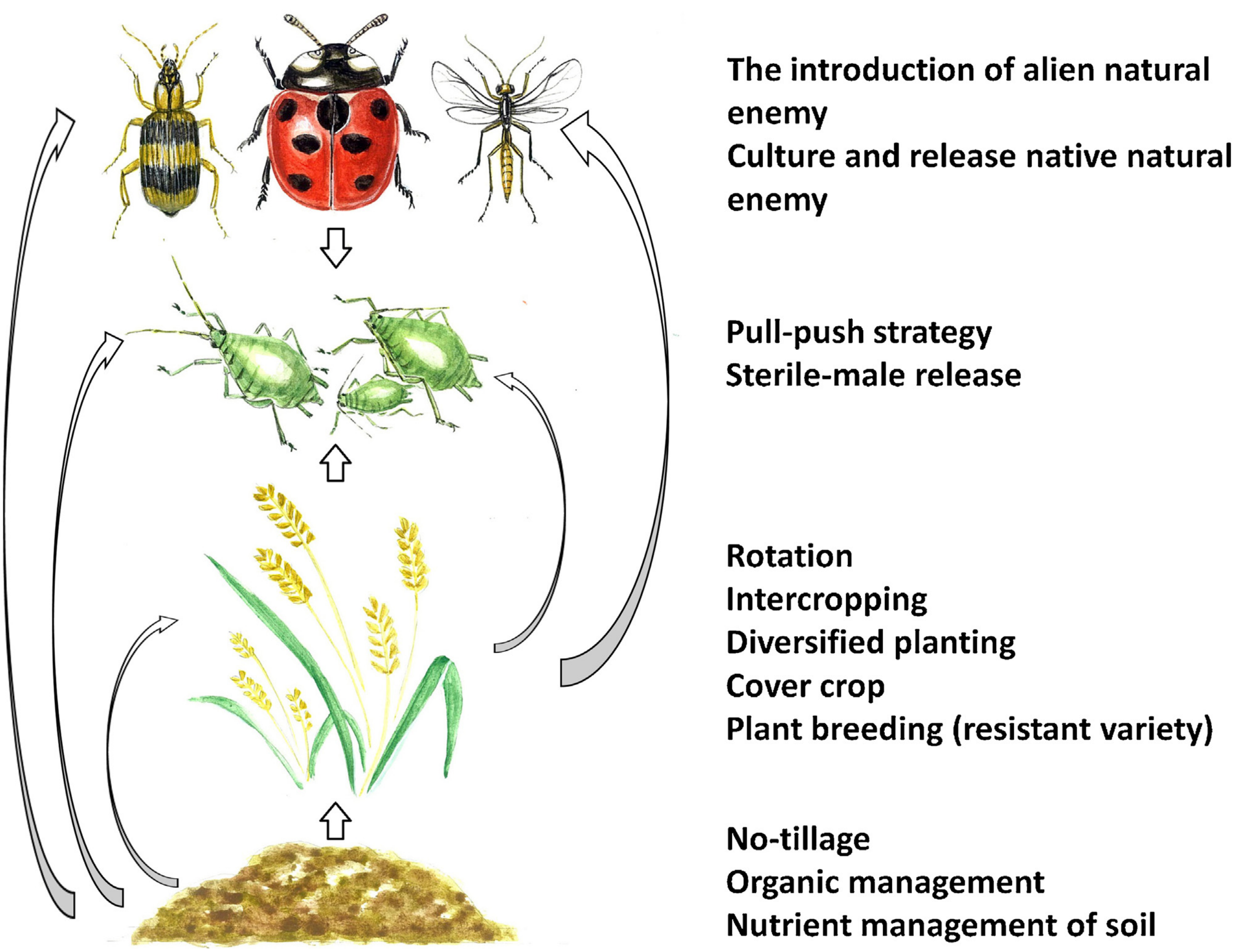

Fig. 2. Practices and technologies of ecologically based pest management within the field.

methods based on a pest's economic threshold that have been used to lower pesticide use (Kogan, 1998; Parsa et al., 2014). However, environmental issues and global changes have created an urgent need for greater use of EBPM (Matson et al., 1997). Therefore, while the use of IPM could effectively control some pest species, the absence of using conventional pesticides in IPM might permit the emergence of other non-targeted pests. Since the composition of pest species can shift with the use of particular technologies, a mixture of cross-disciplinary approaches based on sound ecological principles are important for the success of EBPM (Brevault et al., 2014; Table 1). Several EBPM technologies, including functional plants (companion plants, repellent plants, barrier plants, indicator plants, trap plants and banker plants), crop rotation, no tillage, and resistant breeding have been successfully developed in the past few decades (Atkinson et al., 2012; Parolin et al., 2012; Table 1).

In addition, plant breeding technology (increased hairiness, higher tannins, removal of plant nectars) has also contributed to EBPM, especially in the creation of pest-resistant and pathogen-resistant varieties (Smith and Clement, 2012). Additionally, many resistant crop varieties have been developed by using traditional breeding technology. Herbivore-Induced Plant Volatiles (HIPVs) produced by functional plants can also be used to repel/attract pests or attract their natural enemies. The presence of some functional plants near crops may also produce potential volatile signals that warn adjacent plants of impending pest attack (Cook et al., 2007; Khan et al., 2008). Bank plants (such as alfalfa, *Medicago sativa* L.) adjacent to crop field can provide habitat for natural enemies in winter and allow enhanced migration back into crop fields when pest populations increase (Straub et al., 2014). Meanwhile, managing soil health as a means to achieve plant health has brought a bottom-up approach to IPM (Scherber et al., 2010; Haas and Defago, 2005; Chaparro et al., 2012). Besides, a healthy soil can produce healthy crops with minimal agrochemical inputs. A healthy soil will also have favorable biological, physical, and chemical properties that should support many ground-dwelling predators that further increase the level of biocontrol of agricultural pests (Altieri, 1999; Hiltpold et al., 2012; Jiménez-Díaz et al., 2015). In contrast, poor soil may cause crops to emit stress signals to potential attackers, thereby increasing the risk of pest damage (Bernard et al., 2012; Razinger et al., 2014). Crops grown in healthy soil with favorable aeration and water availability demonstrate greater resistance to and tolerance of agricultural pests (Smith et al., 2013; Schmidt et al., 2014). For example, crops growing in friable soils with adequate aeration are more resistant to pests than those growing in compacted soils (Altieri and Nicholls, 2003b; Tscharntke et al., 2012a). Thus, plant health and soil health are the two most important aspects of EBPM (Zehnder et al., 2007; Chaplin-Kramer et al., 2011; Chaparro et al., 2012; Ehrmann and Ritz, 2014). Therefore, both above- and below ground management should be simultaneously conducted to achieve EBPM.

In a bottom-up strategy, a large number of habitat management technologies, both below- and aboveground, can be used. Aboveground tactics include crop rotation, diversified planting, cover crops, organic farming practices and plant breeding. Belowground tactics include nutrient management and no-till techniques (Table 1, Fig. 2). Biologically healthy soils harbor many different organisms, including nematodes, springtails, insect larvae, ants, earthworms, and ground beetles, as well as micro-organisms like bacteria, fungi, and protozoa (Altieri 1999; Altieri and Toledo, 2011). Crop rotation and no-till agricultural practices can also improve the soil micro-environment to attract natural enemies or suppress pests (Geiger et al., 2011).

Gagic et al. (2012) argue that components of insect communities may be affected differently by crop nutrition and fertilizer inputs, causing shifts of community structure over time among trophic levels (parasitism and predator-prey ratio) and affecting food web structure (link density, vulnerability, and generality). Bianchi et al. (2013), meanwhile, reported that the transition from conventional to organic management may lead to higher pest populations than in either conventional fields or fields with extensive use of organic practices. The decreasing pesticide application and stable environment in organic management could improve natural enemy diversity and crop resistance, which would then suppress pests (Deguine and Penvern, 2014; Marcotegui et al., 2015; Marliac et al., 2016).

Various planting strategies can also be used to control pest population. Plants chosen for specific management roles, including banker plants, barrier plants, companion plants, indicator plants, insectary plants, repellent plants, and trap plants (sometimes called secondary plants) can all be used in crop fields to enhance biocontrol of pests (Parolin et al., 2012; Zhao et al., 2015). While use of functional plants is a promising strategy, further studies are needed to assess the different applications of each functional plant group and it potential to provide EBPM.

3.2. Landscape-scale practices for EBPM

Studies have examined the effects of landscape patterns on pest abundance and natural enemy diversity (Elliott et al., 2002; Brewer and Goodell, 2012; Bianchi et al., 2013) (Table 2, Fig. 3). Kruess (2003) found that non-crop habitats such as pasture and woodlands could enhance species diversity and natural enemy abundance at the landscape scale. Menalled et al. (2003) showed that both parasitism and natural enemy diversity were higher when non-crop habitat accounted for >20% of an agricultural landscape. Elliott et al. (2002) reported that heterogeneous landscapes had higher abundance of ladybird beetles, increasing predator/prey ratios in a complex landscapes. However, spatial

Table 1
The habitat management of ecologically based pest management at the field scale.

Technology	Process and mechanism	References
Crop rotation	Cut off or disturb pest population cycles; destroy the breeding habitat of pests.	(Akhtar and Malik 2000; Rowe et al., 2013; Rusch et al., 2013)
Crop diversity or intercropping	Associated resistance; disturb the progress of pest hosts.	(Andow 1991; Lin 2011; Ratnadass et al., 2012)
Cover cropping	Enhance the activity, abundance, and species diversity of natural enemies by providing alternative hosts and refuges.	(Bugg and Waddington 1994; Altieri 1999; Mediene et al., 2011)
Plant breeding	Increasing physical, chemical, and biological crop resistance through screening tactics.	(Ahuja et al., 2010; van Bueren et al., 2011)
Nutrient management	Reduce free amino acids and nitrogen in crop to enhance resistance.	(Cook 2000; Landis et al., 2000; Mediene et al., 2011; Quilty and Cattle 2011)
No-till techniques	Build the internal environment, structure, and moisture of soil to suppress pests.	(Neuenschwander 2001; Soane et al., 2012; Wezel et al., 2014)

Table 2
The habitat management of ecologically based pest management at the landscape scale.

Technology	Possible process and mechanism	References
Sow flowering plants	Attract parasitic wasps and provide food resources for natural enemies.	(White et al., 1995; Fiedler et al., 2008; Jonsson et al., 2008)
Plant grass strips	Supply alternative hosts or prey and refuge for natural enemies using functional plants.	(Landis et al., 2000; Denys and Tscharntke 2002; Landis et al., 2005)
Keep 5% of the landscape fallow	Increase non-crop, permanent habitats to enhance biodiversity and conserve natural enemies, especially when crops are harvested.	(Weibull et al., 2003; Ferron and Deguine 2005; Bianchi et al., 2006)
Patch rearrangement	Enhance activity of natural enemies by connecting permanent habitats.	(Stenseth 1981; Thies and Tscharntke 1999; Pfiffner and Luka 2000)
Design green-blue net in agroecosystem (a patchwork of different habitats)	Disturb the host location of pests while establishing overwintering conditions and sanctuary for natural enemies through landscape modification.	(Ostman et al., 2001; Brewer and Elliott 2004, Steingrover et al., 2010)

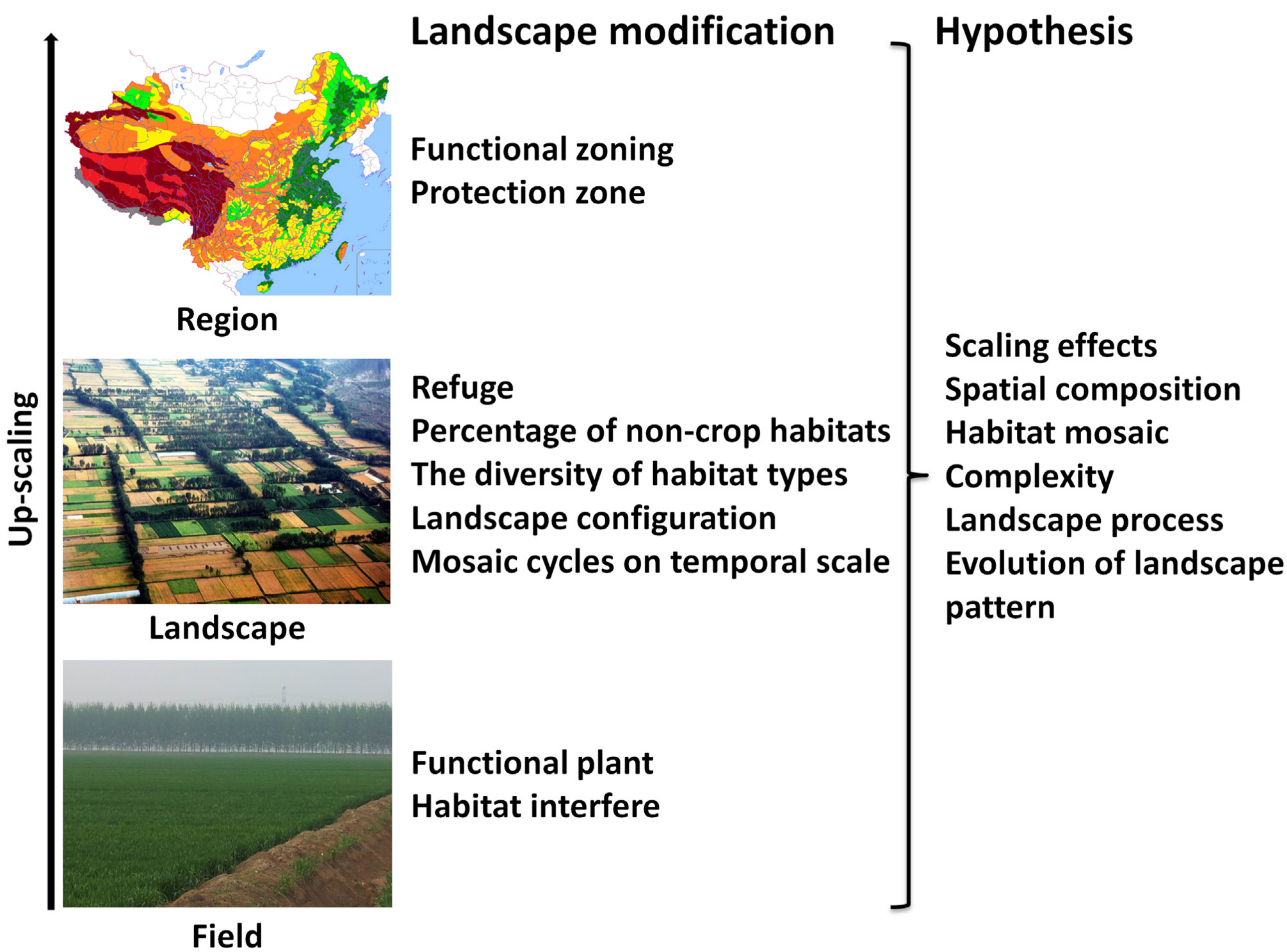

Fig. 3. Landscape modification in ecologically based pest management and associated up-scaling effects in the agricultural landscape.

scale was an important factor in each of these effects, suggesting that different tactics should be applied at multiple spatial scales (Fig. 3).

At a regional scale, landscape simplification caused by cropland expansion can lead to a loss of biocontrol and decreased biodiversity (Roland and Taylor, 1997). Decline in the heterogeneity of agricultural landscapes has also rearranged the habitat patches within the changing landscape pattern (Steingrover et al., 2010). EBPM has paid particular attention to how species composition and pest abundance is changed by the redistribution of plant resources and refuges in agricultural landscapes (Jonsson et al., 2014). Many studies have reported that increasing landscape complexity increases the abundance and diversity of natural enemies and reduces population density of agricultural pests (Gonthier et al., 2014; Zhao et al., 2014). Non-crop patches supporting alternative hosts or prey in complex landscapes act as reserves of natural enemies after crop harvest (Schellhorn et al., 2014), and such structurally complex landscapes with more refuges provide more stable and continuous habitat for natural enemies for overwintering (Landis et al., 2005; Zhao et al., 2013a; Schellhorn et al., 2014; Bynum et al., 2015). For example, artificially sown patches or strips of flowering plants are important sources of forage for bees and natural enemies, and also provide undisturbed pesticide-free habitats for parasitoids and predators (Scheid et al., 2011; Gurr et al., 2012; Wratten et al., 2012). Such flower fields can enhance the abundance of biocontrol agents associated with the ecological management of agricultural pests (Geneau et al., 2012). Clough et al. (2005) found that the species richness of ground-dwelling predators was higher in heterogeneous landscapes than homogeneous landscapes, suggesting spatial heterogeneity at a broad scale to be an important driving force in enhancing spider (and other predator) diversity in agroecosystems. The diversity and richness of natural enemies can therefore be enhanced to achieve biocontrol of agricultural pests by changing the agricultural landscapes (Tscharntke et al., 2012b). Many other researchers have found that landscape complexity can facilitate species diversity of natural enemies and sustainable management of agricultural pests (Gardiner et al., 2009; Gardiner et al., 2010; Winqvist et al., 2011; Veres et al., 2013). However, some researchers have reported that increased landscape complexity had no significant effect on pest damage, or even slightly increased pest densities. D'Alberto et al. (2012) also found that permanent habitats, including pasture and woody vegetation, had no significant correlation to the abundance of spiders at the landscape scale. Vollhardt et al. (2008) also reported that landscape complexity had no significant effect on the species diversity of parasitic wasps in wheat fields. In the past decades, most research on this topic has focused on relationships between landscape patterns and biodiversity, abundance and richness, while inter-species relationships and intraguild interactions among natural enemies received less attention (Landis et al., 2000; Burel et al., 2013).

Pest abundance may be another important cause driving changes to the natural enemy community in a gradient of landscape complexity, which has sometimes been neglected when the effects of landscape patterns on natural enemy communities have been analyzed (Borkhataria et al., 2012; Veres et al., 2013). Furthermore, different natural enemy groups (such as parasitic wasps, leaf- and ground-dwelling predators) may show different responses to landscape patterns, suggesting that landscape complexity may benefit some species while having no effects on others at a specific scale (Rand and Tscharntke, 2007; Diehl et al., 2013). The effects of host density and species on natural enemies should therefore be examined in further research (Schmidt et al., 2003; O'Rourke et al., 2011).

Over the past decade, researchers have proposed several hypotheses (resource conservation hypothesis and natural enemy hypothesis) of how pest populations might be regulated, such as the top-down and bottom-up processes that act to limit herbivore densities (Root, 1973; Landis et al., 2000; Tscharntke et al., 2012b). These regulating forces can be grouped into four mechanisms with respect to how landscape patterns affect pest population management (Fig. 3).

First, in several studies, plant distribution and the spatial arrangement of landscape pattern was the key influence in determining the level of biocontrol of the studied pests (e.g., Tscharntke et al., 2002; Schmidt et al., 2008). In addition, only certain plant species–those which supply pollen, nectar, shelter, or over-wintering habitat for natural enemies–enhanced biocontrol (Balzan and Wackers, 2013). Flower strips along field margins and inter-sowing cabbage fields with flowers are examples of some practices used to promote increased numbers of ground-dwelling predators as well as general arthropod biodiversity (Ditner et al., 2013).

Second, in other cases, the spatial and temporal dynamics of the landscape mosaic may significantly affect pest's population dynamics (Chaplin-Kramer et al., 2013). Most agricultural pests in arable land need to emigrate out of crop fields in autumn and return to crop fields in spring. Similarly, some natural enemies need several different habitats to complete seasonal their life history (Blitzer et al., 2012; Veres et al., 2013; Zhao et al., 2015). Seasonal population fluctuations of the mango fly (*Anastrepha obliqua*) (Macquart) (Diptera: Tephritidae) indicated that *A. obliqua* migrate among several orchards for food search and oviposition sites over time, as different fruits mature (Aluja, 1994). Another example of habitat switching is that of a parasitoid (*Aphidius avenae*) (F.) (Homoptera: Aphididae) of cereal aphids, which as an adult needs to feed on nectar of wild flowers as an adult and yet also must enter grain fields to search for host aphids during its egg laying period (Zhao et al., 2013a). Even entomophagous predators (e.g., carabid beetles) may need heterogeneous landscapes to complete their life cycle, with larvae stages depending on perennial or undisturbed habitats (Coombes and Sotherton, 1986). Thus, movement is critical to escape from temporary disturbances and to find resources scattered in space and time (Bishop and Riechert, 1990; Schellhorn et al., 2014).

The third mechanism, landscape connectivity (habitat net), is a useful index for assessing landscape patterns, as increasing connectivity can enhance the biocontrol of agricultural pests (Thies and Tscharntke, 1999; Baguette et al., 2013). For example, landscape connectivity can shift habitat arrangements (physical mosaic patterns), thus changing the population density of coffee berry borer (*Hypothenemus hampei*) (Ferrari) (Coleoptera: Curculionidae) after cropland expansion and simplification (Avelino et al., 2012). In European canola (*Brassica napus* L.) (Brassicaceae) fields, high landscape connectivity enhances the abundance and spread of important parasitoids (*Meligethes* spp.) Stephens (Coleoptera: Nitidulidae) of the key pest (*Meligethese aeneus* F.) (Coleoptera: Nitidulidae), of the crop, leading to higher levels of parasitism (Thies et al., 2003). While some researchers have found landscape complexity to have no significant effects on natural enemies (Menalled et al., 2003; Vollhardt et al., 2008), most have found that low connectivity of landscape pattern suppressed biocontrol (Kruess, 2003; Tscharntke et al., 2007; Zhao et al., 2014). A network of semi-natural non-crop landscape elements in an agricultural landscape can enhance biocontrol and biodiversity by providing various resources for the survival of beneficial insects that suppress crop pests but require resources in non-crop habitat patches (Steingrover et al., 2010)

The fourth mechanism by which landscape patterns affect pest levels is that loss of semi-natural habitats in an agricultural landscape has a negative effect on natural enemies (Hunter, 2002; Benton et al., 2003; Rand et al., 2006). With the expansion of cropland expansion and agricultural intensification, non-crop habitats have dramatically decreased (Crowder and Jabbour, 2014; Rand et al., 2014), compromising their ability to sustain a diversified community of natural enemies and resulting in the decline of key biocontrol agents and an increased possibility of outbreaks of some pests (Kruess and Tscharntke, 2000; Ratnadass and Barzman, 2014). High loss of key habitats may disrupt the relationships between pests and their natural enemies, and decreasing levels of biocontrol through reducing refuges or overwintering habitats in agricultural landscapes (With et al., 2002). Therefore, habitat loss may cause distribution and diversity of natural enemy while habitat fragmentation (connectivity) affect upper trophic species (like parasitoids) to disappear from an area before it affects herbivores like tephritid flies because the latter are stronger fliers. This then provides a mechanism to distinguish the effect of habitat loss from lack of connectivity, with the latter being more a question of distance not among patches of the non-crop habitat but distances between crops and non-crop habitat (Aluja et al., 2014).

4. Recent progresses in EBPM at multiple spatial scales

Although increasing agrochemical inputs and cropland expansion have greatly enhanced certain ecosystem services (chiefly crop yield) over the past several decades (Altieri et al., 2012), this same agricultural intensification has decreased other ecosystem services (such as biodiversity conservation and biocontrol) (Batary

Table 3
Ecological services supplied by insect community.

Ecological services	Possible process and mechanism	References
Biocontrol	Enhance pest population management through intraspecific relationships and complementary effects.	(Tscharntke et al., 2005; Bianchi et al., 2006; Jonsson et al., 2008)
Pollination	Increase crop yield through pollination.	(Fiedler et al., 2008; Tscharntke et al., 2007)
Decomposition	Facilitate material cycles and energy flow by increased species diversity of ground-dwelling arthropods.	(Swift et al., 2004; Zhang et al., 2007; Diekotter et al., 2010)
Resource insects	Contain abundant nutrition and provide food and medicine for humans.	(Altieri 1999; de Groot et al., 2002; Losey and Vaughan 2006)
Culture	Arts, cultural heritage, and inspiration	(Zhang et al., 2007; Fiedler et al., 2008)

et al., 2012; Bianchi et al., 2013). In the last 50 years, environmental pollution (Brewer and Goodell, 2012), biodiversity loss (Geiger et al., 2011), soil degradation (Benayas and Bullock, 2012), and lack of food security (Tscharntke et al., 2012a) have become global issues, making habitat management at both the local and regional scale a crucial strategy (Brewer and Goodell, 2012; Macfadyen et al., 2012; Tscharntke et al., 2012b). There is an urgent need for sustainable pest control and crop production methods that can allow croplands to provide multiple ecosystem services that are being lost with the current agricultural practices (Losey and Vaughan, 2006; Fiedler et al., 2008; Jonsson et al., 2014) (Table 3). For example, the pollination service can be enhanced by increasing honeybee in landscapes with a high percentage of semi-natural habitats. In addition, insects could provide culture services (defined as aesthetic values, recreation and ecotourism) such as those used in arts and cultural heritage (Table 3). A multiple scale approach, appropriately adjusted to fit field, landscape and regional needs, could regulate a plant-pest-natural enemy system through habitat design at both the landscape and agricultural field levels, enhancing crop production and soil conditions (Krawchuk and Taylor, 2003; Gonthier et al., 2014).

This article has mentioned several technologies for potentially enhancing pest control, at either the field or landscape scale, through enhanced healthy of under- and above ground (soil and crop). How to integrate these technologies to achieve better pest control remains a relatively unexplored area (Robert, 2002; Weibull et al., 2003; Rusch et al., 2013). Multidisciplinary methods (incorporating agronomy, plant breeding, ecology and geographical information) may provide an effective avenue to achieve agricultural sustainability and multiple ecosystem services (Ratnadass et al., 2012; Woltz et al., 2012; Smith et al., 2013). The use of habitat management has recently been extended to provide multiple ecosystem services addressing both regional and local environmental issues (Kleyer et al., 2007; Batary et al., 2008; Brewer and Goodell, 2012). However, past IPM has generated an incentive dilemma between IPM activities aimed at enhancing yields for individual farmers and IPM activities aiming to provide long-term benefits for the region as a whole (Kogan, 1998).

As advanced habitat management methods have become available in agroecosystems, ecologists have been challenged to reconcile the additional costs and risks of these techniques with the long-term benefits that accrue to regional landscapes rather than to just individual landholders. Habitat management aiming to achieve common goals beyond the short-term should consider the multifunctional benefits (trade-off effect) – both market- and environment-based – of sustainable agriculture (Brewer and Goodell, 2012). In addition, pest population management should consider both crop habitats and adjacent non-crop habitats, as the surrounding landscape may have strong effects on natural enemy distribution (Tscharntke et al., 2012a). However, farmers have little or no control over other land use in the larger landscape. It may be difficult to "design" landscapes to enhance pest control because of conflicting objectives by groups or individuals, other than farmers, living in the landscape. So, the government should encourage collaboration of multiple fields and carry out economic tactics such as compensation for loss of some subsidies (Steingrover et al., 2010). Regional projects that required all farmers in specific development areas to adhere to rules governing when the key crop was planted, harvested, and residues destroyed. Additionally, resistance management programs for resistant crops that requires some acreage be planted to non-resistant versions of the crop. This is also the regional community's benefit rather than just the individual farmer (who may suffer some yield loss in the short run in the non-resistant part of his planting) (Carroll et al., 2012).

There is a growing consensus among ecologists that landscape pattern and habitat composition affect biotic interactions and interspecific relationships (Golden and Crist, 1999; Brewer and Goodell, 2012). It has become increasingly clear that insect distribution and abundance, as well as population dynamics, trophic interactions and community composition within a particular habitat may all depend on the patterns and processes of the larger surrounding landscape (Krawchuk and Taylor, 2003; Zhao et al., 2013b).

Habitat management can greatly affect the population dynamics of pests and natural enemies in agricultural landscapes (Brewer and Elliott, 2004). Changes to any landscape's structure and process can affect a natural enemy's ability to control a pest, a process supplied by landscape ecology (Thies et al., 2003). Therefore, qualitatively relationship between landscape structure and biocontrol provided by natural enemies would provide appropriate landscape design and modification could achieve EBPM, especially with the rapid development of modern information technology (Zhao et al., 2012).

5. Conclusion

The coordinated development of economic and environmental factors is one of the most important characteristics of habitat management, which could be used to achieve multiple ecosystem services. Any single technology will not completely control pest damage. For example, while one particular pest could be managed by one pest-resistant cultivar crop, new secondary pests can sometimes become the main pests (Ahuja et al., 2010). To better understand this phenomenon, future studies should examine the arthropod community and arthropod-plant interactions, which has been called the full-quantitative food web method (Van Veen et al., 2008; Plecas et al., 2014). EBPM aims at enhancing regional environment across multiple spatial scales while the conventional IPM largely focuses on the agricultural management within fields (Kogan, 1998; Altieri and Nicholls, 2003b). Sustainable agriculture currently faces a great challenge from global environmental changes, and the solution to this challenge requires joint forces from farmer associations and landowners (Ostman et al., 2001). To this end, the government needs to make policies promoting the farmer-to-farmer cooperation and coordinated management. Ecologists and agricultural scientists could also publicize their science through sufficient education and training so that the gap between individual goals and social benefit can be narrowed (Brewer and Goodell, 2012).

Few studies have examined the relationship between pest management and the food web structure of the arthropod community (Kruess and Tscharntke, 2000). In order to understand the effects of landscape pattern and agricultural practice on the population dynamics of specific species, it is vital to measure the shift of the arthropod food web caused by human activity. In the future, the arthropod food web structure at a large scale and its energy flow characteristics will become some of the most important issues for pest population management in sustainable agriculture (Jonsen and Fahrig, 1997). The interacting and mutually reinforcing processes of agricultural practice within the field, and landscape design at the landscape level contribute to EBPM through quantitative food web and energy flow modification that have important implications for agricultural sustainability and other environmental issues (Cumming et al., 2014; Gonthier et al., 2014).

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